Bifenthrin Dislodgeable Foliar Residues Following Reduced-Volume and Conventional Pesticide Applications in Greenhouses

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Summary

Dislodgeable foliar residues of bifenthrin were monitored following three types of low volume pesticide application equipment used in nursery and greenhouse operations. These applications were compared to a dilute or full coverage spray. Low volume, high concentration sprays may produce higher dislodgeable residues and increase exposure to workers entering treated areas. Applications were conducted at a nursery raising citrus stock for ornamental and agricultural use. The low volume applications were conducted at use rates suggested by the manufacturers. The low volume equipment included a coldfogger, air-assisted electrostatic handgun and pulsefogger, while the dilute application was completed with a hydraulic sprayer. The rates were 812, 1015, 2030, 115 µg of bifenthrin per cm^2 of bench area treated, for the coldfogger, electrostatic hand gun, dilute sprayer and pulsefogger, respectively. The DFR levels within each treatment were relatively similar over the first week of the study. The theoretical initial deposition for the coldfogger and electrostatic handgun were one third to one half the dilute and correspond to the difference in the amount of actual bifenthrin applied over the treatment area. The pulsefogger applied about one twentieth the dilute amount of bifenthrin with a deposition half the dilute. A second pulsefogger treatment area sampled in the greenhouse resulted in about one fifth the foliar residues found from the dilute foliage samples. This was because these were older plants with much denser plant foliage. Under the conditions of this study the reduced-volume applications did not increase the dislodgeable foliar residues. An absorbed daily dosage of 0.020 mg per kg of body weight was calculated for a female worker with an average weight of 61.5 kg. From these residues it can be expected workers entering greenhouses after expiration of the 12-hour reentry interval would not be exposed to greater residues than current dilute applications.

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Introduction

Traditionally, nursery greenhouse pesticide applications have used spray equipment requiring high volume and high pressure sprays. However, spray technology has changed and spray equipment is now available that uses less volume and often at lower pressure. In a review by Pimentel et al. (1986), researchers found that a spray boom with the nozzles directed downward, on a calm day, will place 90% of the spray in the target area while only 50% of the pesticide reaches the target in aerial applications.[1] When measurements of ground applications are directed at how much pesticide impinges on the target pest they find less than 1% of the applied material eventually reaches the pest. Sufficient pesticide is usually applied to make up for this difference with label dosages making up for variation in application techniques and conditions. Certain reduced-volume technologies control the size and uniformity of the droplets precisely. Electrostatic nozzles put a slight negative charge on each spray droplet (charge to mass ratio about -6.0 mC/kg). While the plant is considered neutral because it is in the ground there are slight positive charges on the plant surface. Additionally since the charge droplets have the same polarity they repel each other and do not coalesce, allowing for better distribution within the target area. Fogging applications also reduce spray volumes, increase distribution within the target area due to the smaller droplet, reduce the amount of active ingredient required and allow for a great reduction in application time.

Giles et al. (1992), compared reduced-volume electrostatic technology to a conventional dilute application (full coverage spray) in a greenhouse using permethrin at 1.15 kg active ingredient applied to chrysanthemums.[2] His study showed a greater than 3-fold increase in foliar deposition using the reduced-volume electrostatic application. Mass balance and pesticide recovery analysis showed 59% of the electrostatic application reached the target foliage compared to 16% for the conventional application. The authors concluded application rates could be reduced three- to four-fold.

Bifenthrin ((2-methyl[1,1'-biphenyl]-3-yl) methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate, CAS No. 82657-04-3) is a broad spectrum insecticide and miticide formulated as an emulsifiable concentrate or wettable powder. Bifenthrin is used on a variety of field, forage and vegetable crops under the trade name Capture®. For greenhouse grown ornamental trees, shrubs, plants, flowers, non-bearing fruit and nut trees, bifenthrin is sold as a flowable insecticide under the name Talstar® T&O. A category III pesticide carrying the signal word "caution," it has a restricted entry interval of 12 hours.

Increases in foliar deposition can potentially lead to increases in worker exposure while performing cultural practices. This potential for increased worker exposure with an increase in dislodgeable foliar residues (residue that can be removed by washing the surface of the leaf with a water and surfactant solution) has been investigated and shown to be correlated.[3,4,5] Dislodgeable foliar residue (DFR) is expressed as micrograms per square centimeter of leaf surface ($\mu g/cm^2$). Greenhouse production of plants is labor intensive and some crops require frequent pesticide applications with an inherent increase in likelihood of workers contacting recent residues. While reduced-volume spray technologies have been shown to increase foliar deposition[2], this result implies a reduction in the amount of pesticide applied to achieve efficacy. This study compares the DFR levels of three different reduced-volume technologies and a dilute application.

Material and Methods

The four types of application equipment used included three low volume sprayers and one dilute sprayer. Two "glass-covered" greenhouses were used for the treatments. Three applications took place in one greenhouse using three benches per treatment. Each bench was 5 by 48 feet equaling 240 square feet (1.5 m x 14.6 m = 22 m^2), with up to 2300 plants per bench. The application order was coldfogger, electrostatic and dilute. Three benches were between the coldfogger and electrostatic spray gun. There was one bench between a single bench of the dilute application and the electrostatic treatment with two additional benches across the 2.5-m-wide center aisle to complete the dilute application. During the applications drift from the dilute application was observed occurring to the outside row of the electrostatic treatment. No sampling of this outside row occurred except in error on day 13. No observable drift occurred for any of the other treatments but no samples were taken between applications to confirm this. A fourth treatment using a pulsefogger sprayed another entire greenhouse 189 by 108 feet (57.6 m x 32.9 m). Two areas within this greenhouse were selected for sampling. One had plants that were 8-month-old seedlings and the other area had 14-month-old plants. The application rate for the dilute application was taken from the registered label and commonly used by the grower. The low volume applications used conversions provided by the manufacturer of the spray equipment. The "tank mixtures" were applied at the rates of 80 gal/ac (748 L/ha), 9 gal/ac (85 L/ha), 600 gal/ac (2271 L/ha), and 3.4 gal/ac (32 L/ha) for the coldfogger, electrostatic handgun, dilute or full coverage spray, and the pulsefogger, respectively. Application information for the formulated product and active ingredient (a.i.) is reported in Table 1.

Table 1.
Bifenthrin Application Information[\a]

Application type	Talstar T&O rate-(ounces)	Bifenthrin (grams a. i.)	Bifenthrin (µg/ cm^2) [\b]	Water gallons	Tank mix analysis (%)	Percent of expected	Unused mixture
Coldfogger	2.4	5.4	812	5	0.11	102	< 0.2 G
Electrostatic gun	2.5	5.7	1015	1 pint	1.26	107	< 0.01 G
Dilute sprayer	6	13.5	2030	50	0.01	93	~40 G
Pulsefogger	9.6	21.7	115	6[\c] (L)	0.32	89	< 0.2 (L)

\a Treatments were to 720 sq ft of bench surface except the pulsefogger treated 20,000 square feet.
\b Application information is amount of bifenthrin in µg per area of bench surface treated in cm^2 (µg/ cm^2).
\c Pulsefogger used 4 L water and 2 L VK-II fogging solution.

The 600M Mini Coldfogger (Dramm International, Manitowoc, Wis.) produces spray particles in the range of 30-40 microns. This coldfogger uses an electric motor that drives a hydraulic diaphragm pump that produces up to 3000 psi to atomize the spray. The design of the coldfogger allows chemicals to be applied at low volumes but can be used for high volume applications. The range in droplet size increases to 100 to 150 microns when using the high volume method. The electrostatic hand gun is commercially available and uses air atomizing, induction charging with battery pack and compressed air attachment. The gun is manufactured by ESS, Inc. and is licensed from the University of Georgia. The electrostatic handgun produces droplets 30 to 60 microns in diameter with an air line pressure at 40 psi, air volume of 10 CFM and a liquid pressure less than 15 psi. The droplet charge to mass ratio is about -6 mC/kg. The dilute or full coverage spray application was made using a Myers hydraulic sprayer operating at 300 psi equipped with a handgun having a Tee Jet nozzle producing a cone spray pattern. For these three applications the applicator made one pass for each side of the three benches. From the center aisle the applicator walked up between the benches and started the spray operation working back to the center aisle. The applicator would then again walk between the same benches and spray the other side, again working backward. Six passes would be made to spray the three benches. For the coldfogger application the six passes took 3.4 minutes

to complete. The electrostatic gun application took 3 minutes but only five of the six passes were completed because the material ran out after five passes. Therefore the application rate using this method is slightly higher than that calculated by the manufacturer. These application times count only the actual time spraying and not the time it took to walk back up the rows to begin each pass. For the dilute application the average pass time was 1.2 minutes and the job was completed in nine minutes.

The last application used a pulsefogger, model K-3, Dramm International, Manitowoc, Wisconsin. Previous measurements have shown this fogger to produce 70% of its droplets in the range of 7 - 15 μm.[6] This fogger heats the material and creates a pulsing action to atomize the droplets. The applicator walked down the main aisle oscillating the fogger back and forth over the benches and up and down between the benches, spraying the entire greenhouse in 11.5 minutes. The greenhouse vents were kept closed until the following morning when they were opened for ventilation for one hour. After the one-hour ventilation the vents were closed and allowed to function normally for temperature control. Two locations were sampled from this greenhouse. One had primarily 14-month-old budded trees and the second consisted entirely of 8-month-old seedlings.

Bifenthrin, sold as Talstar® T&O flowable, EPA# 279-3105, is formulated at 7.9% and contains $^{2}/_{3}$ pound active ingredient per gallon. All applications took place on September 24, 1996 after the workers left for the day at 1700 hours and were completed by 1830 hours. The four types of applications were completed within one hour of the first application. Sampling began 12 hours after the last application and was followed up with re-sampling at 1, 2, 6 and 13 days. DFR sampling was conducted according to established procedures.[7,8]

For four of the sites sampled, a 2.523 cm diameter Birkestrand® leaf punch was used to take the samples and each sample consisted of 40 punches with four samples per interval. For the fifth site and the second area in the greenhouse treated with the pulse fogger, a 1.25-cm-diameter Birkestrand® leaf punch was used and 80 punches were collected because of the small leaf size on the seedling rootstock. Punches were taken randomly throughout the plant canopy. All leaf discs were collected in four-ounce glass jars attached to the punch. Each sample jar was capped with a Teflon-lined lid, labeled, bagged, and placed on ice in an insulated chest. Samples were shipped on ice to the California Department of Food and Agriculture, Center for Analytical Chemistry (CDFA) laboratory the day of collection. Plants were not irrigated until after the day six sampling. At this time the greenhouse treated with the pulsefogger was irrigated by an overhead sprinkler system for one hour. The other three treatment areas were irrigated by using a wand on the end of a hose. The watering of an area would be complete in a few minutes.

Samples were analyzed for bifenthrin. Leaf disks were shaken three times with 50 mL 0.05% sodium dioctyl sulfosuccinate solution, the combined amount of water was then extracted three times using 50 mL ethyl acetate. The organic extract was then dried by anhydrous sodium sulfate. The samples were analyzed by gas chromatography using an electron capture detector on a Hewlett-Packard 5880A chromatograph. The chromatographic conditions were: column HP-5, 25 m length x 0.2 mm inside diameter x 0.33 μm film thickness. Instrument temperatures were: 250, 250 and 350 ^{o}C for the oven, injector and detector, respectively. Using these conditions, the retention time for bifenthrin was 10.00 minutes. Standards were introduced periodically during the analysis. The limit of detection for bifenthrin was 1 μg per sample (0.0025 μg/cm^{2}). Laboratory recoveries from fortifications of blank extracts were 101% at 4.01 μg/mL and 97% at 10 μg/mL. Recoveries were within established limits and no corrections of the data were performed.

Analytical results reported in micrograms per sample were divided by the surface area of the leaf punches (400 square centimeters). Data analysis used Microsoft Excel© version 7.0a Analysis Toolpak for descriptive statistics, analysis of variance and to perform the linear regressions on the natural log of the data. Fisher's Least Significant Difference test was used to evaluate the difference between groups.

Results

Figure 1 shows the theoretical decay rate of DFR for the four different application methods. Regressions for the electrostatic hand gun and the pulsefogger were performed on the data through day six. For the pulsefogger this is because the two plots were irrigated by overhead sprinkler on day seven for one hour. This overhead irrigation likely washed off residues and influenced the degradation of bifenthrin. For the electrostatic handgun the one outside row that received observable drift at the time of the dilute application was sampled in error on day 13 creating an additive effect to the residues.

The estimated parameters used to plot the curves for each application are given in Table 2. The low r^2 values suggest the data may not be well described by the fitted decay curves. The observed data from each treatment are plotted on graphs in Appendix 1. The DFR levels within each treatment were relatively similar over the first week of the study; this can be seen by the similar means and standard deviations reported in Table 3.

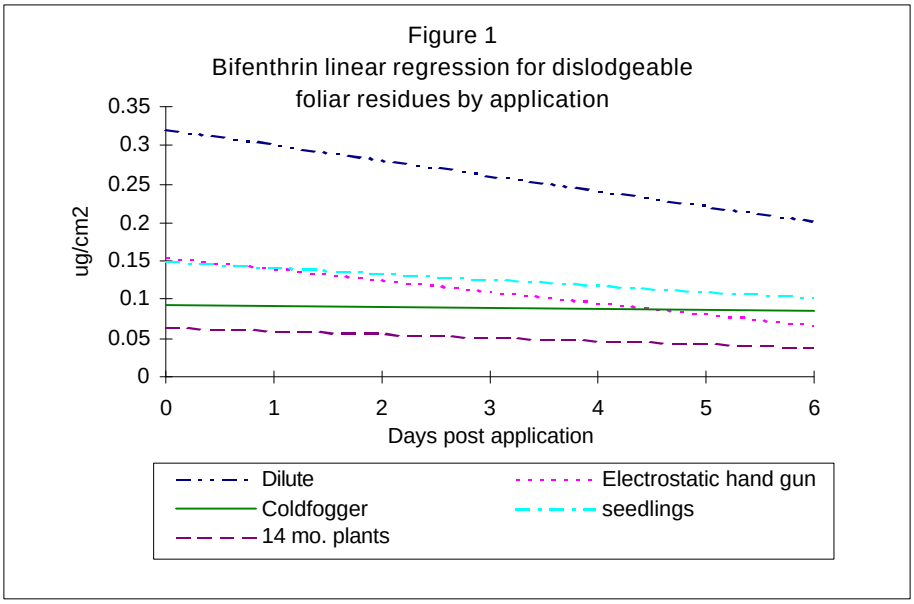

Table 2. Summary of regression analyses for bifenthrin

Application Type	Theoretical initial deposition[a] ($\mu g/cm^2$)	Decay rate ln ($\mu g/cm^2$)	r^2	Half-life days
Dilute	0.32	-1.136	0.60	9
Electrostatic gun	0.15	-1.868	0.37	5
Pulsefogger 8 mo. seedlings	0.15	-1.897	0.44	11
Pulsefogger 14 mo. plants	0.06	-2.735	0.20	8
Coldfogger	0.09	-2.362	0.05	49

[a]predicted by the regression analysis using data through day 13 for the dilute and coldfogger applications. Data through day 6 used for pulsefogger applications because of overhead sprinkler irrigation and for the electrostatic application because of sampling error on day 13.

Table 3. Mean and standard deviation for bifenthrin dislodgeable foliar residues reported in $\mu g/cm^2$

		Application Type				
Days post application	N	Dilute	Electrostatic handgun	Pulsefogger 8 mo. seedlings	Pulsefogger 14 mo. plants	Coldfogger
0.5	4	0.32 ± 0.011	0.21 ± 0.111	0.16 ± 0.014	0.09 ± 0.004	0.10 ± 0.034
1	4	0.27 ±0.023	0.13 ± 0.054	0.12 ± 0.015	0.05 ± 0.016	0.11 ± 0.020
2	4	0.25 ± 0.032	0.09 ± 0.020	0.14 ± 0.011	0.05 ± 0.014	0.08 ± 0.011
6	4	0.27 ± 0.041	0.08 ± 0.025	0.11 ± 0.022	0.04 ± 0.013	0.08 ± 0.026
13	4	0.12 ± 0.076	0.22 ±.0.049[\a]	0.01 ± 0.003[\b]	0.01 ± 0.001[\b]	0.09 ± 0.033

\a One row that received drift from the dilute application was sampled in error on day 13 creating an additive effect to the residues.
\b These two plots were irrigated by overhead sprinkler on day seven for one hour.

There was a significant difference between groups at p=0.00012. The deposition of the dilute application was significantly higher than all other application methods except for the electrostatic method at α=0.01. The only other significant difference in application methods was between the electrostatic and the 14-month-old plants treated with the pulsefogger.

Discussion

Application rates were those suggested by the manufacturers of the equipment. The Talstar® T & O label does not specify the application rate per unit area but as ounces per gallon with recommendation to apply as a full coverage spray. The amount of active ingredient used was approximately half that of the dilute or full coverage spray for the coldfogger and electrostatic handgun. The theoretical initial deposition shown in Table 2 for these two applications is one-third to one-half the dilute. This corresponds to the difference in the amount of bifenthrin applied over the treatment area. The pulsefogger applied about one-twentieth the dilute amount of bifenthrin with an observed deposition of half that for the dilute application for the 8-month-old seedlings at twelve hours post-application. These seedlings are 2-3 feet tall and the foliage is not dense compared to the other treatments. In contrast, the 14-month-old plants had very dense foliage and the observed deposition was about a quarter of the dilute. The graph in Figure 1 also shows the pulsefogger did not penetrate the dense foliage of the 14-month-old plants as effectively as for the eight-month-old seedlings. DFR levels for the older plants were less than half that of the 8-month-old seedlings.

Brouwer, et al. (1992)[9,10,11] conducted exposure studies of reentry workers in floriculture in the Netherlands. They targeted high volume application "because the former is crop directed and thus will lead to higher deposition"[9]. They measured dermal exposure of 44 workers while cutting after spray applications. Dong (1996)[12] used the data of Brouwer to develop a dermal transfer factor for California of 7000 µg/hr dermal residues per µg/cm^2. In California, DFR is traditionally calculated based on two sides of the leaf[7]. A 90% protection factor is assumed for clothing because workers wear long pants and long-sleeved shirts[13]. The dermal transfer factor is determined from the transfer of surface residue of the foliage to the skin.[3,4] The transfer factor is dependent upon the amount of residue available and the frequency and intensity of contact with the treated crop. This transfer factor has been used to predict dermal exposure to field workers entering treated fields. Using this transfer factor, the dermal exposure of workers to bifenthrin can be estimated to be 21.7 mg/hr (0.31 µg/cm^2 $*$ 7000 µg/hr dermal residues per µg/cm^2) or 17.4 mg per 8-hour work day at the 12 hour reentry for the full coverage spray application. The dermal absorption has been calculated to be 18%[14] which would give an absorbed daily dosage of 0.051 mg per kg of body weight (17.4 $*$ 18%/61.5) for a female worker with an average weight of 61.5 kg. This absorbed dose was calculated using the average of the dilute application at 12 hours, the highest DFR levels found. This calculated exposure is less than half the level reported by Dong (1996)[12] because of the lower foliar residues found in this study.

This study was designed to provide information on dislodgeable foliar residues that could be used in assessing worker exposure. During the study period the applications were not evaluated for insect pressure. Hall (1991)[15] in a comprehensive review found "in general a close relationship between drop size, drop density, concentration, and their effect upon pest mortality, i.e., small (drop size) is usually more effective on an array of pests. This relationship can be dependent upon both the pest species, its ecology, and the specific attributes of the pesticide and its formulation." Droplets less than 100 µm were deposited more efficiently on the lower leaves. The number and size of droplets may have as much or more to do with bringing about control than the amount of actual toxicant in a given area. The cooperator stated that the pulsefogger application rate used in this study is normally used in their greenhouse. The manufacturers of the spray equipment were also of the understanding that bifenthrin use rates in this study were within the range of application rates commonly used by other growers. For the pulsefogger application the grower stated that the 14-month-old plants would usually be moved out of the greenhouse and not be treated by this method. The tank mixture (water or diluent plus pesticide) applied over a given area is much greater for the dilute application ranging from 30:1 to a high of 175:1 for the pulsefogger. One study[2] has shown a significant increase in off-target deposition using full coverage spray applications. This is due to the larger droplets and high velocities used in the dilute or full coverage spray application that tend to pass through target areas and deposit on floor surfaces.

Under the conditions of this study, foliar residues from the reduced-volume applications were lower than those of the dilute application. Foliar residues may vary with plant height and foliage density, changing the amount of available plant surface area. For example, field applications to citrus, which has a dense outer canopy, often use higher gallonages to penetrate the foliage. When plants are packed closely together on the benches as they were in this study, the dense canopy may influence penetration of the pesticide to the inner leaves, resulting in lower foliar residues. The seedlings treated with the pulsefogger had a sparse canopy. For these plants the application rate was substantially less, accounting for lower foliar residues than for the dilute application.

References

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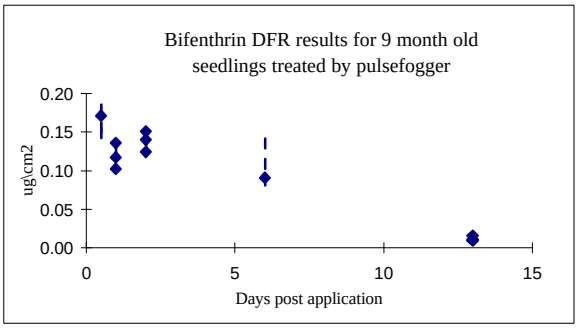
Appendix 1


Bifenthrin DFR results for 9 month old seedlings treated by pulsefogger
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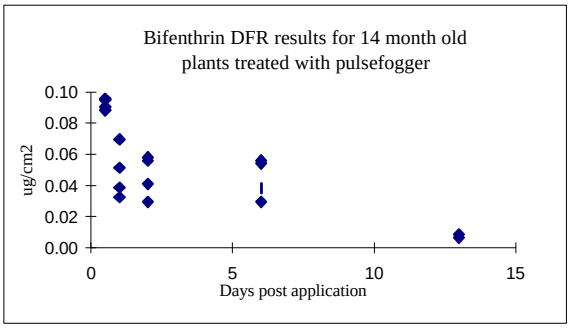
0.15
0.10
0.05
0.00
0
5
10
15
Days post application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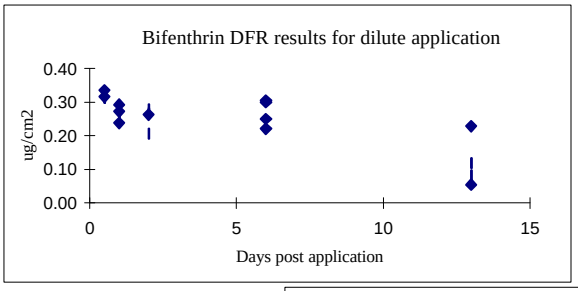
0.02
0.00
0
5
10
15
Days post application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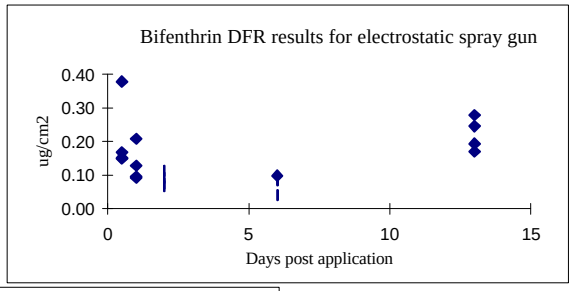
0.20
0.10
0.00
0
5
10
15
Days post application


Bifenthrin DFR results for electrostatic spray gun
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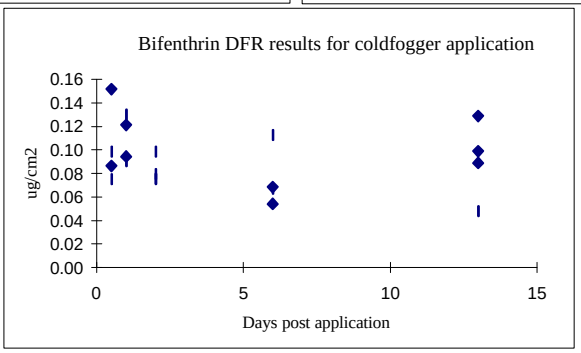
0.10
0.00
0
5
10
15
Days post application


Bifenthrin DFR results for coldfogger application
ug/cm2
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
5
10
15
Days post application